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FOUR FUNCTION CALCULATOR USED TO AUTOMATICALLY COMPUTE WAVELENGTH

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FOUR FUNCTION CALCULATOR USED TO AUTOMATICALLY COMPUTE WAVELENGTH*

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ABSTRACT

An inexpensive four function calculator is being used to calculate the wavelength of spectral lines on photographic plates measured with an optical comparator. The computations are made repetitively from the digitized screw position of the optical comparator in 0.8 seconds. The duration of the displayed wavelength is variable from 0.3 to 3 seconds. Although our system already has a semi-automatic card punch system for processing data via a computer, the instantaneous calculation and presentation of wavelengths of spectral lines is of great value.

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INTRODUCTION

The four function calculator is a low priced instrument which has found its way into many homes offices and laboratories. Almost all calculators have features such as fixed or floating point decimal point, ability to do chain arithmetic operations following mathematical formulas, left hand entry, suppress leading zeroes, eight or more digit display, and ability to present negative numbers. A calculator is capable of doing arithmetic operations at millisecond speeds. We wanted to take advantage of the low cost and the many features built into such a calculator for calculating the wavelength of spectral lines on photographic plates.

Although all precise wavelength calculations are made by fitting data to a polynomial equation in a compter program, it is often desirable to quickly know the wavelength of some spectral line or whether there is a line at some known region. An on-line wavelength calculation while the spectrum plate is still on the optical comparator and the spectral line or region is still in view greatly assists the operator. The spectral lines of interest are photographed on diffraction grating spectrographs. The uniformity of the reciprocal linear dispersion (plate factor in angstroms per mm) of radiation obtained with such instruments is of great practical use and is the basis of the calculation with the device described here.

The optical comparator in use at this laboratory has a precisely machined screw which can position a spectrum line of a photographic plate to a precision of one micrometer (10^{-6} meter). The screw position is digitized via an optical encoder which can be readily mounted on most comparators.

When measuring wavelengths which increase with distance from left to right, which we call the normal mode, the wavelength (λ) is given by the equation:

$$\lambda = (d - d_1)\ PF + \lambda_1 \qquad (1)$$

where

$$PF = \text{plate factor} = \frac{\lambda_2 - \lambda_1}{d_2 - d_1} \quad , \tag{2}$$

λ_1 = wavelength of first known spectral line

λ_2 = wavelength of second known spectral line

d_1 = digitized screw position of first known spectral line

d_2 = digitized screw position of second known spectral line

d = digitized screw position of unknown spectral line

Occasionally we must measure plates where the wavelengths decrease with the distance from left to right. We call this the reverse mode and when this occurs we use the following equation:

$$-\lambda = (d - d_1)\ PF - \lambda_1 \tag{3}$$

where the answer in the calculator is given as a negative number. This takes advantage of the feature in the calculator which presents negative numbers and makes our job easier in the design of the controller described below. The negative sign of the result is ignored by the user.

We have built a controller which takes the digitized screw position and does the equivalent of pushing the calculator keys at the appropriate time and in the proper sequence. Thumbwheel switches are used to enter the constants d_1, PF and λ_1. It takes approximately 0.8 second to complete one calculation. The result (λ) is repetitively computed and displayed for a duration adjustable from 0.3 to 3 seconds for the operator's convenience.

A. Calculator Characteristics

We will discuss the calculator[†] characteristics which concern us in the design of the controller. The calculator uses metal oxide semiconductor (MOS)

[†]Master Calculator Model A-1, Grand Prairie, Texas 75050.

devices applied in large scale integration (LSI) to perform the arithmetic operations. The calculator is a desk top unit which affords room for the modifications required to interface the calculator to the controller. The unit has 16 digit capability although it can display only the most significant 8 digits or the least significant 8 digits at one time via an alternate display key. It has left hand entry, suppresses leading zeroes, has fixed decimal point adjustable to seven positions, displays negative numbers and does chain arithmetic operations. Calculator speeds measured with a pulse generator are 1) addition and subtraction less than 10 milliseconds, 2) multiplication approximately 200 milliseconds, 3) less than 15 milliseconds delay required between entering of two numerals or functions, and 4) one millisecond pulse required to enter a function or numeral. Power requirements are 115V ac, 60 Hz.

B. Modifications to the Calculator

We made modifications to the calculator in such a way that the modifications would not impair the normal operation of the calculator and that the power requirements demanded of the calculator would be negligible. Figure 1 shows the typical drive circuit used to enter the function or numeral into the calculator. The field-effect transistor (FET) Q_2 parallels the normally open key contact and is driven on via a pulse of 1 ms duration. The transistor Q_1 is normally off and is driven on, which in turn drives the FET. Since both Q_1 and Q_2 are normally off, they draw no current except when they are pulsed requiring a minimum of power. The gate of the FET is at the junction of the 510 kohm and the 24 kohm resistors because we have to soften the turn-on of the FET and not drive the gate of the FET too close to ground potential. This feature is vital because the contacts of the keyboard (and the drain and the source of the FET's) operate at approximately minus 12 volts potential, and the operation of the calculator is impaired when the gate of the FET is driven too close to ground potential, interfering with the minus 12 volt circuit.

The minus 20 volt supply (not shown) is derived from the calculator power supply and draws negligible current even when the transistors are pulsed on. Since the transistors are normally off, it should be evident that the calculator can be used normally as long as the controller is not operating or is disconnected. A multi-pin connector is used to bring the 16 signals from the controller. The 16 signals correspond to the calculator functions (+), (-), (×), (=) and CLEAR, the numbers 0 thru 9, and the decimal point.

C. The Controller

The function of the controller is to enter the functions and the digital information into the calculator at the proper time and sequence. Figure 2 is a flow diagram showing the program sequence used in the controller. It should be evident that the flow diagram follows the mathematical Eqs. (1) and (3). A program counter is used to keep track of the steps, and these steps are indicated on the flow diagram. At steps 1, 3, 5 and 7 a subroutine is used to enter the numerical information. The flow diagram for the subroutine is shown in Fig. 3. A subroutine counter is used to keep track of steps in the subroutine. All of the numbers entered have three significant places to the right of the decimal point. Not all of the numbers have seven digits, but in order to keep the subroutine simple, the controller enters leading zeroes for those numbers requiring less than seven digits. Since the calculator has left hand entry and ignores leading zeroes, the only loss is a few milliseconds in the computation cycle.

Figure 4 shows a simplified diagram of the program used to sequence the various functions and enter the numbers at the proper time. This diagram corresponds to the flow diagram in Fig. 2.

With switch 1 (S-1) in the stop position nothing happens, and the calculator can be used in its usual manner. The stop position is also the reset position where both the program counter and the subroutine counter are reset. When the program counter is reset, the decoder output is at the (CLEAR)' step position. As soon as the start/stop switch is thrown to the start position, the 1 ms strobe is actuated sending a CLEAR signal to the calculator and simultaneously triggering a 20 ms delay. At the end of this delay the program counter is incremented by one, setting up the d' step position.

The d' step position marks the entry into the subroutine program which is shown in the simplified diagram in Fig. 5. This diagram corresponds to the flow diagram in Fig. 3. The d' signal initiates a strobe pulse to the gate control while directing the (d) signal from the optical comparator into the shift register. A 1 ms strobe is then generated to strobe into the calculator the most significant decimal digit (MSD) after the decoder has selected the proper line (0 - 9). After a 15 ms delay the subroutine counter is advanced to step 1 which causes the shift register control to shift all the digits up one decimal digit toward the MSD. The next most significant digit is now in the MSD location, and the 1 ms strobe is again generated to send the proper numeral to the calculator. After a 15 ms delay the subroutine program counter is advanced, and the cycle continues in a similar manner until step 4 when the subroutine program directs the 1 ms strobe to the decimal point gate where a decimal point is entered in the calculator. The cycle resumes and strobes in the remaining numerals until step 8 is reached, marking the exit from the subroutine. Step 8 is also used to reset the subroutine program counter.

After exiting from the subroutine, re-entering the main program, and waiting out a 20 ms delay, the program counter is advanced to step 2 which initiates the 1 ms strobe. The strobe sends an arithmetic function (-) command to the calculator, and again after a 20 msec delay the program counter is advanced to step 3 (d_1') which marks entry into the subroutine program. The d_1 information from the thumbwheel switches is sent to the calculator in a manner described above for entering the d information.

The program continues in a similar manner entering the function (x) and the constant (PF) into the calculator until the program counter reaches step 6. At this step a (+) or (-) function is sent to the calculator which is determined by the position of switch 2 (S-2) located on the front panel. The switch must have been thrown to the proper position to correspond to the type of plate being measured, i.e., normal or reverse plate. It is at this time that the actual multiplication process is done in the calculator. Since the multiplication process takes as long as 200 ms, the 200 ms delay is generated instead of the 20 ms delay to await advancement of the program counter.

The program continues until step 8 when the (=) function is sent to the calculator. The answer, or wavelength, is displayed in the calculator, and the program counter is advanced to step 9. At this time the displayed wavelength is held for a duration of 0.3 to 3 sec which is selectable by the operator. After this delay period the program counter is advanced to step 0 which begins the program cycle anew. The result will repetitively appear on the calculator display until a new position is chosen.

Switches 3 (S-3) and 4 (S-4) are shown in Figs. 4 and 5 allowing one to select run or single-step operation. These diagnostic switches are on the front panel. In the single step position the counters can be incremented by pushing the push button. The single step mode is valuable while debugging the controller, and later for the operator should he wish to reassure himself that the correct numbers and functions are being entered into the calculator.

D. Operation

Figure 6 is a photograph of the finished controller. The controller and calculator as attached to the optical comparator are shown in Fig. 7.

To measure a spectrum reference lines of known wavelength are first marked on the plate which is then carefully aligned on the comparator. The reciprocal linear dispersion or plate factor is determined with a pair of known lines and their positions on the comparator. The calculator can be used in its ordinary mode of operation for this calculation. The reference wavelength, position and plate factor are entered into the controller with the thumbwheels. The normal or reverse switch is positioned depending on whether the wavelengths on the plate being measured increase or decrease with distance. The two diagnostic switches are thrown in the run position. The decimal point is located on the calculator, generally three figures after the decimal. The start/stop switch on the controller is thrown to start, and the wavelength which corresponds to the screw position automatically appears on the display. Measurements can now be made in the region for which the plate factor is applicable.

Although the reciprocal linear dispersion of spectra taken on diffraction grating spectrographs is fairly uniform, there is a gradual change from one end of the plate to the other. For example, a 10 inch spectrum in the first order taken on a 3 meter spectrograph with a grating having 1200 grooves per mm shows a plate factor of 2.769 angstroms per mm at one end, and 2.757 angstroms per mm at the other end. If an average plate factor for the entire 10 inch plate is used, the calculated wavelengths will diverge away from the correct value by as much as 0.43 angstroms at the points farthest from the reference points. Even this kind of accuracy can be useful in initial surveys of plates.

However, of greater interest is this quick calculation of wavelengths within given areas where the plate factor is more accurate for that region. On the same plate described above, over a 30 mm range, the calculated wavelengths are never more than 0.03 angstroms from their true values, and lines nearest the reference points were calculated to better than 0.01 angstrom. From the instant calculation of wavelength or from the computed difference of two wavelength calculations, immediate identification of spectral lines is possible.

The instant wavelength calculation is especially useful when one must bootstrap the reference lines in spectra taken in regions where it is not easy to photograph common reference spectra, such as the vacuum ultraviolet regions. Another common application is to identify lines of impurities which are mixed with lines of known elements. A third application is to search for a line of a given wavelength. To do this one simply watches the calculator display for the wavelength as the plate is moved. The controller is set for the shortest display duration so that one can quickly arrive at the wavelength region of interest. Examination of the plate image at that point will indicate if the line of interest is present.

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FIGURE CAPTIONS

Fig. 1. Typical drive circuit for entering function or numeral into calculator.

Fig. 2. Flow diagram of controller program.

Fig. 3. Flow diagram of subroutine program.

Fig. 4. Simplified diagram for controller program.

Fig. 5. Simplified diagram for subroutine program.

Fig. 6. Controller panel.

Fig. 7. Optical comparator with controller and calculator.

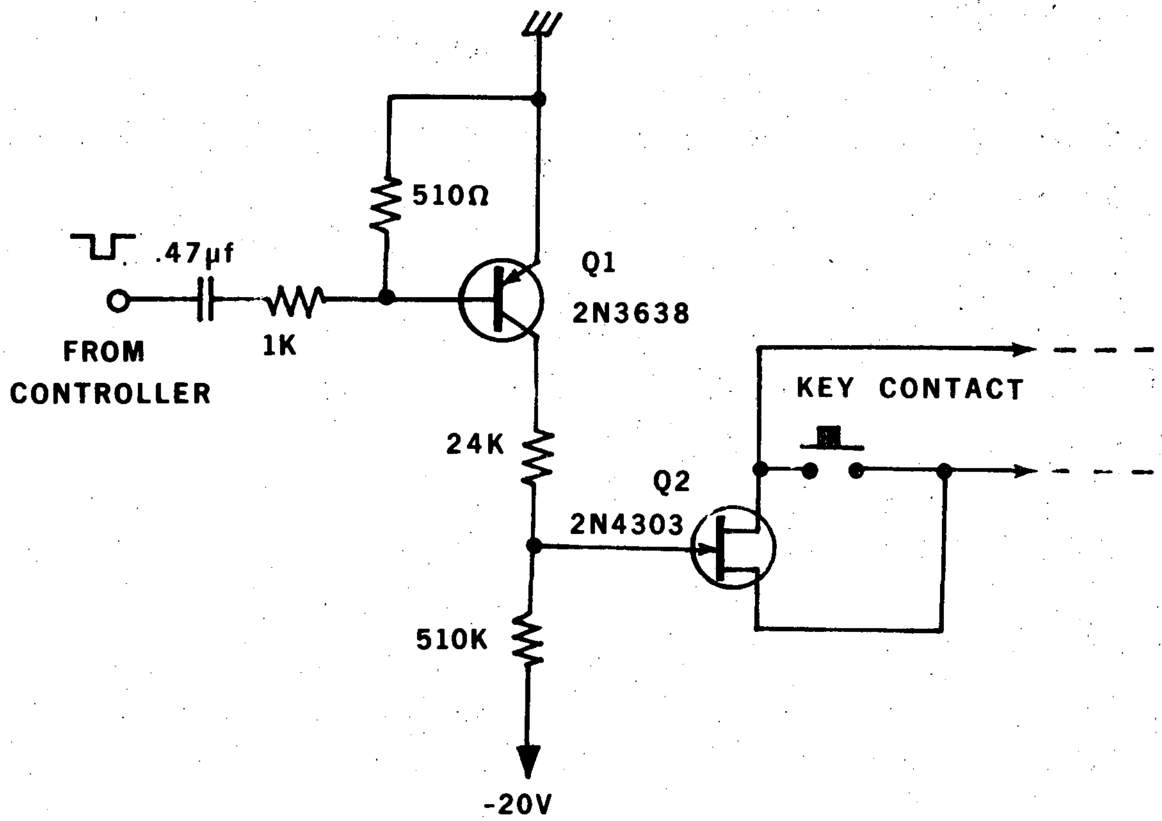

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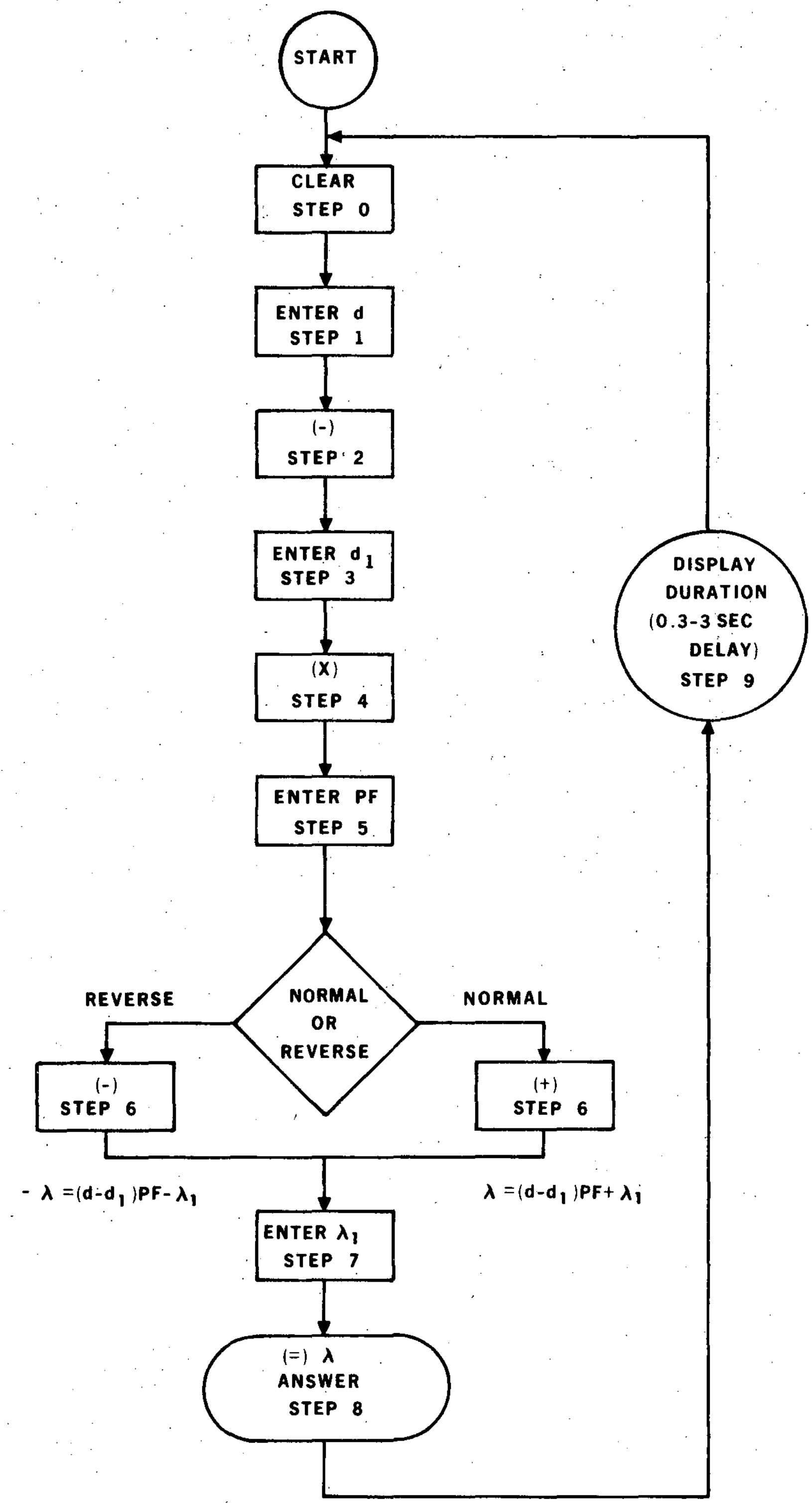
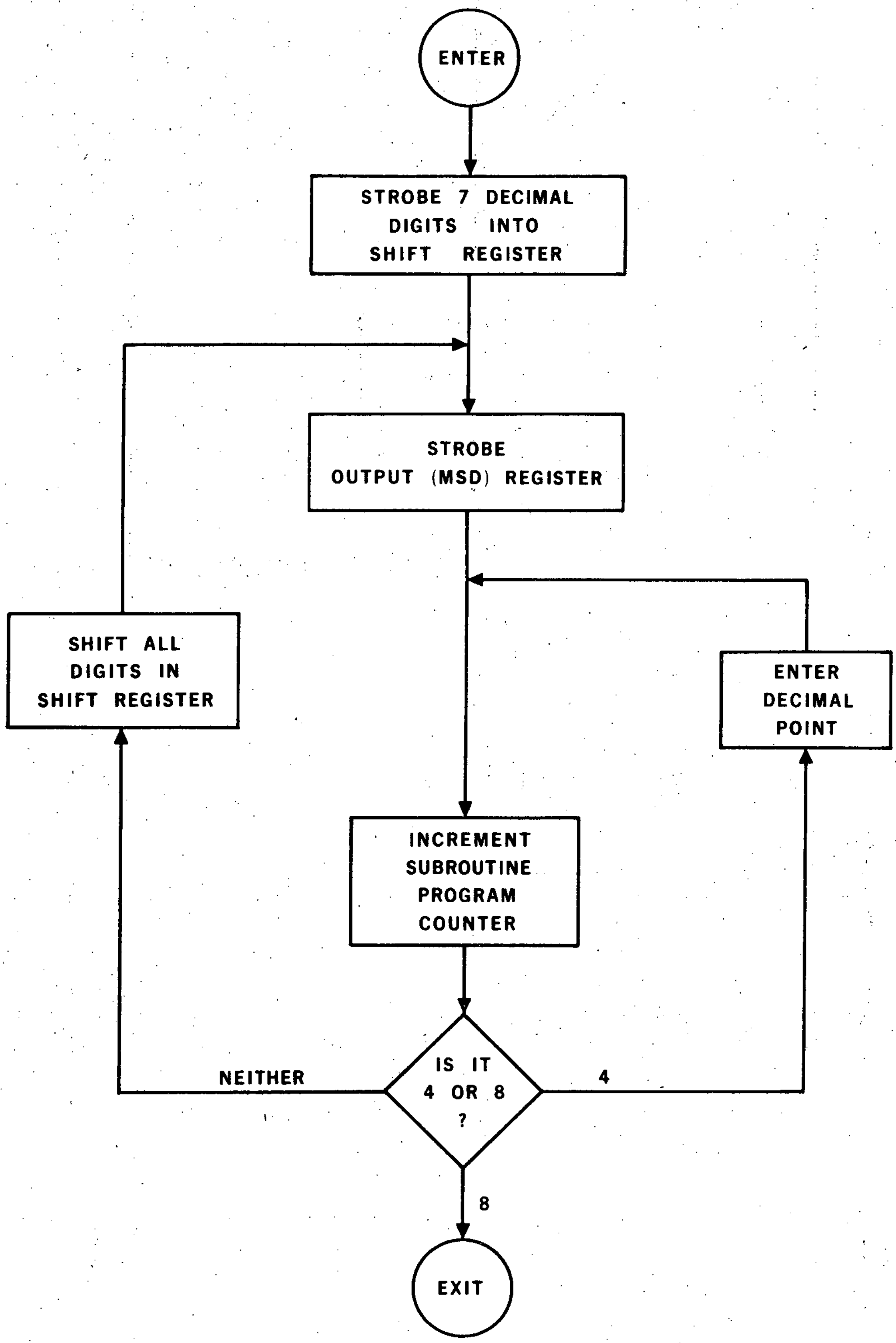
Fig. 1.



XBL 7312-6841

Fig. 2.



XBL 7312-6840

Fig. 3.

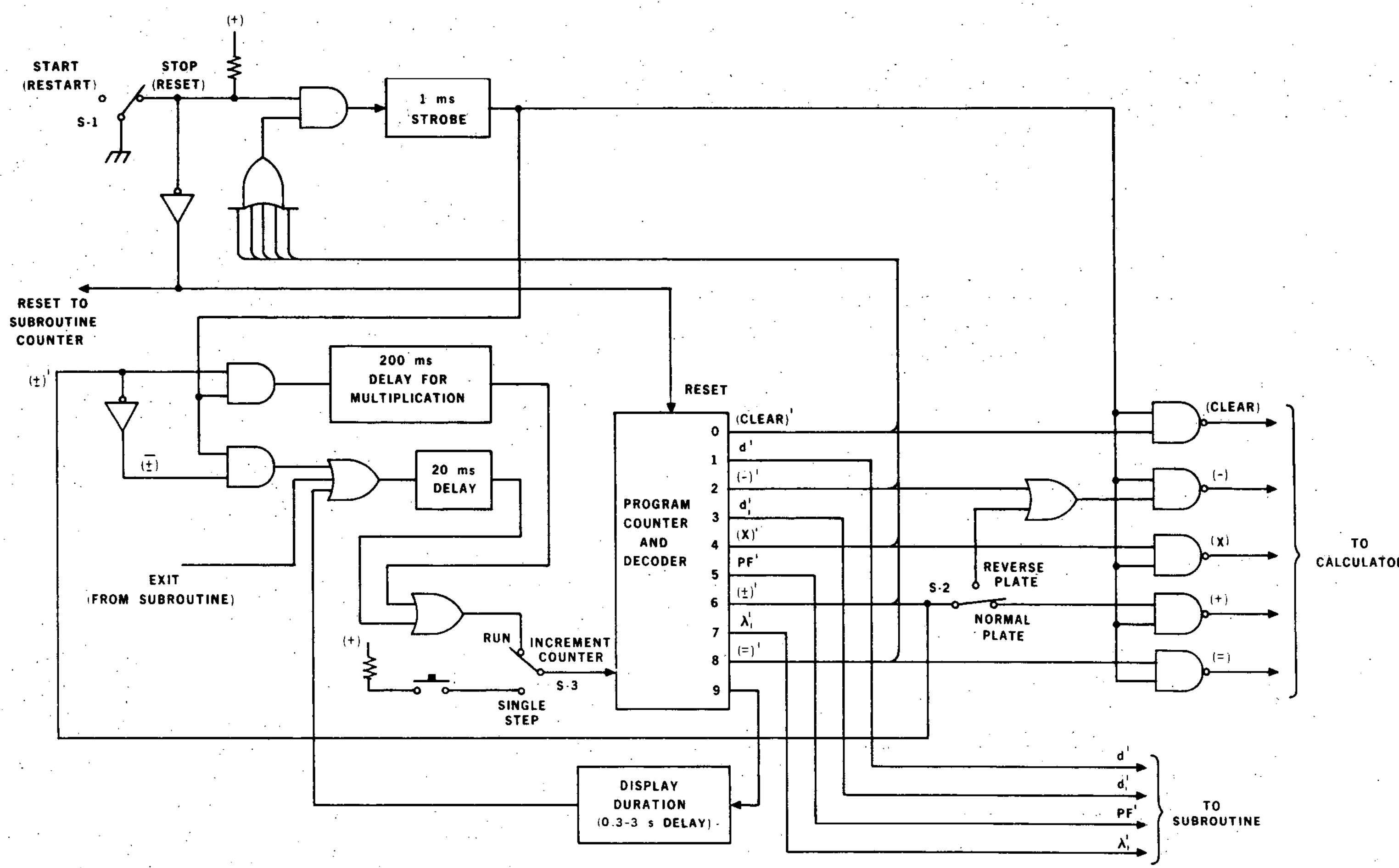


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Fig. 4.

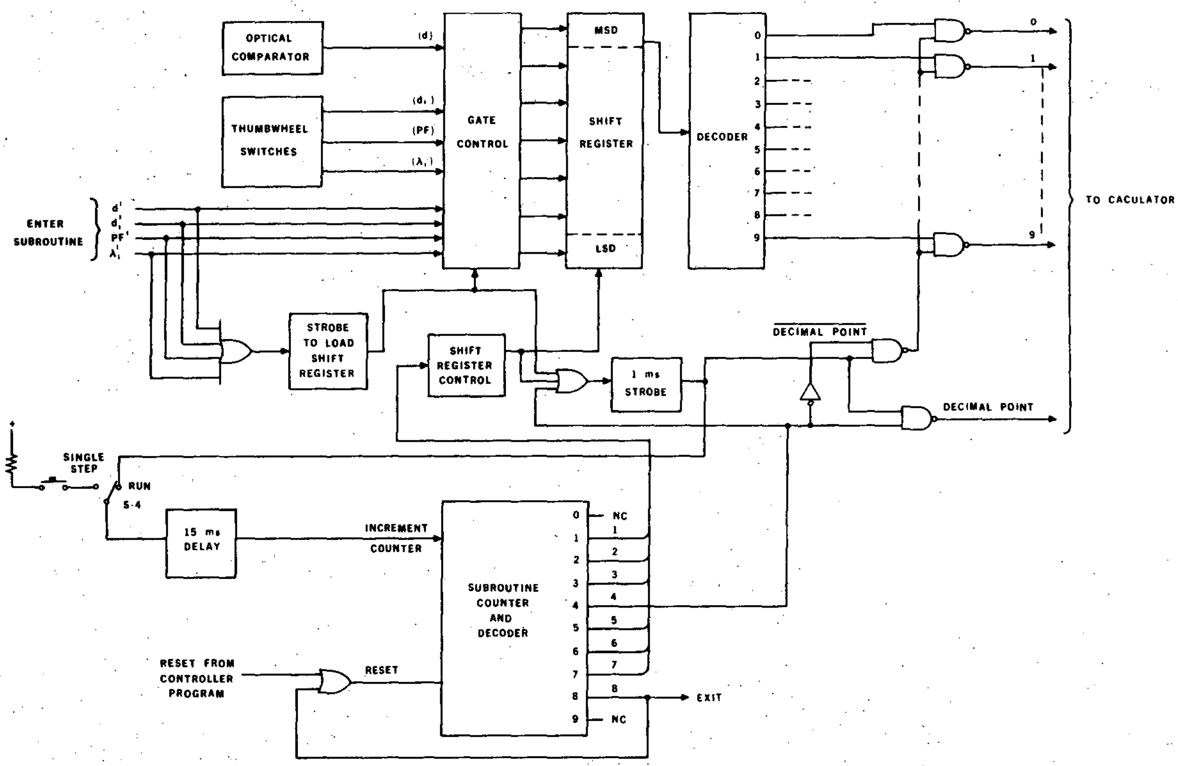

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Fig. 5.

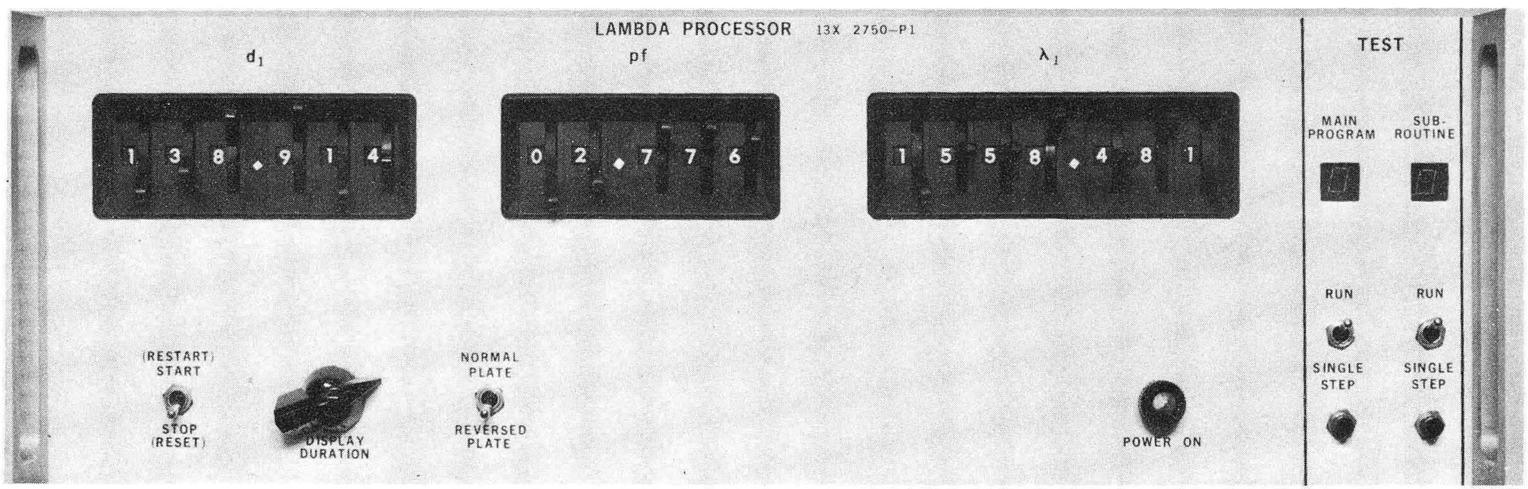

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Fig. 6.

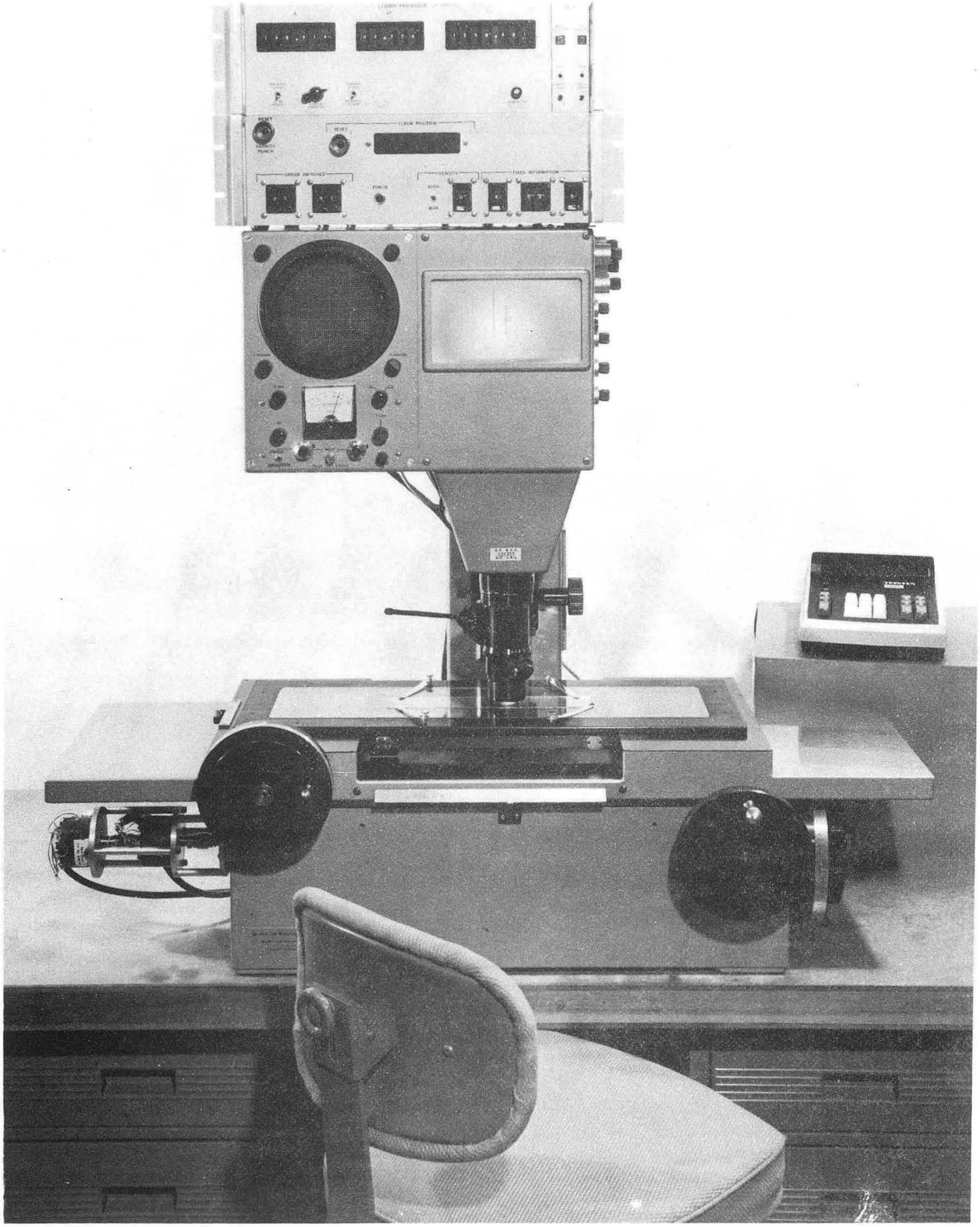

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Fig. 7.

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